Modified Electronic Properties of Nanoscale Polymer Fibers via Nanoparticle Doping with Melt and Solvent Electrospinning

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The ability to synthesize conductive nanoscale fibers from non-conductive polymers with a robust fabrication method allows for a broad utilization of electrospun fibers. Electrospinning (ES) involves the delivery of a liquid polymer to a spinneret that is held at a high voltage relative to a collection plate. Fiber size depends on flow rate, electric current, and the fluid surface tension.[1] To synthesize the conductive fiber, two methods are being researched: (1) melt and (2) solution electrospinning. Melt electrospinning starts with a solid polymer that is heated past its melting-point temperature to create a fluid. Polypropylene (PP) is doped with multi-wall carbon nanotubes (MWCNTs) to increase the conductivity of the PP. This PP-MWCNT compound is then melted and electrospun. Solution electrospinning uses a solution of polymer in solvent. Particularly, Poly(vinyl alcohol) (PVA) in water is used to synthesize the fibers that are subsequently pyrolyzed (heated to high temperature in the absence of oxygen) to increase the conductivity.

In preparation for melt electrospinning, non-ideal MWCNTs and 12,000 M_w PP was combined in a mixing extruder to form a 5wt% PP-MWCNT compound. The resulting compound showed agglomerations of MWCNTs, as shown in the scanning electron microscope (SEM) micrograph of Figure 1. A conductivity test sample was molded. Conductivity of the bulk sample was measured, followed by sample sectioning and more conductivity measurements. The sample was prepared by removing the molded end and subsequently coating the end with colloidal silver; the sample had an average conductivity of 0.441 Siemens per meter. The test sample is shown in Figure 2. Finite element simulation of a molded sample was conducted to provide insight into the temperature distribution in the polymer stick and provide knowledge of time constants for steady-state processing conditions. This sample was electrospun, the resulting fibers exhibited a high electrical resistance. SEM micrographs revealed agglomeration of CNT bundles that are believed to have minimized electrical conductivity in the fibers.

For solution electrospinning, two PVA solutions were used; one solution was a stabilized 4wt% 100,000 M_w PVA, the other solution was a 5wt% 146,000 – 186,000 M_w PVA. Initial trials resulted in a beaded fibrous mat, as shown in the SEM micrographs of Figure 4. Subsequent steps will include the pyrolysis of the PVA fiber mat and conductivity tests.

[1] S. V. Fridrikh, J. H. Yu, M. P. Brenner, and G. D. Rutledge, "Controlling the fiber diameter during electrospinning," Phys. Rev. Lett., Vol. 90, No. 14, April 2003.

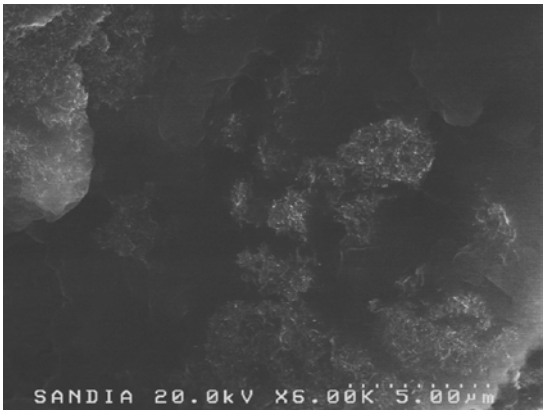

Figure 1: Scanning electron microscope (SEM) micrograph of agglomerated composite. A 12,000 M_w, 4wt% PP/MWCNT composite is shown with agglomerations averaging 1.5 µm in diameter with the sizes ranging from 0.618 µm to 3.066 µm.

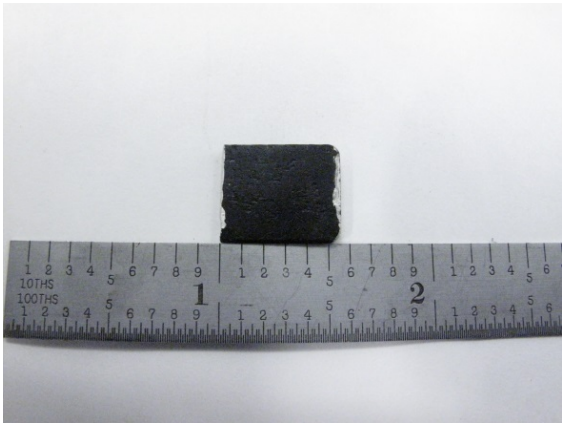

Figure 2: SEM micrograph showing conductive composite material. This sample was synthesized from 12,000 Mw, 4wt% PP/MWCNT and was conductive.

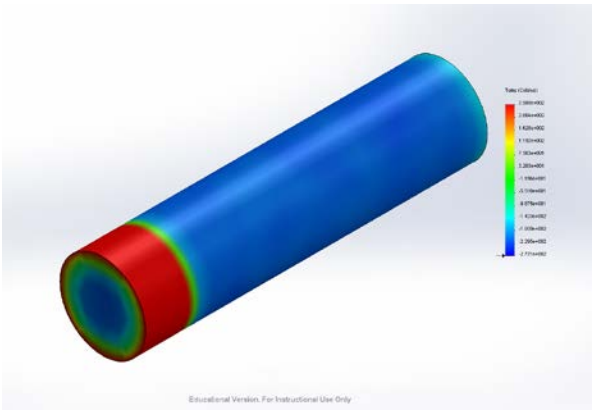

Figure 3: Finite element simulation of temperature distribution in polymer melt ES stick. The circumferential band at the end of the stick was held at a constant temperature of 250 °C.

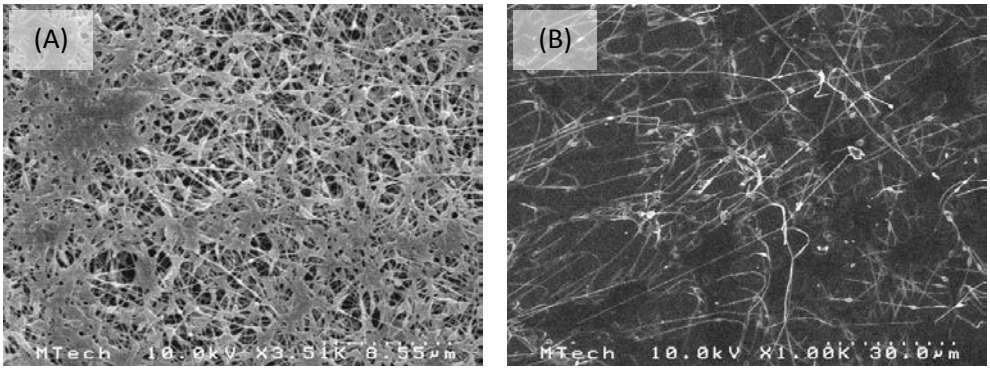

Figure 4: SEM micrographs of electrospun beaded fibrous mat. (A) 100,000 M_w, 4wt% PVA and (B) 146,000 – 186,000 M_w, 5wt% PVA.